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Station Paper No. 154

December 1962

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A Method for Determining the Slope of Neutron Moisture Meter Calibration Curves

by

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The neutron method of measuring soil moisture is coming into use more and more since reliable commercial equipment has become available and is rapidly replacing other methods of determining moisture content. In agricultural and hydrologic studies, moisture content is often measured over a period of time and the changes are related to evapotranspiration and drainage. Because of methods usually employed in gravimetric calibration, there is reason to doubt the accuracy of moisture changes thus determined.

Described simply, the neutron method consists of placing a source of fast neutrons in a soil mass, recording the number of impulses produced in a detector tube by returning slow neutrons, and relating the slow neutron count to the volume of moisture in the soil (1, 2, 5). For commercially available instruments, the relation between moisture and counts is

$$M = a + \frac{1}{b} X \quad (1)$$

where M is moisture content in percent by volume, a is a constant, b is the slope of the curve in counts per percent moisture, and X is the slow neutron count per unit time. Used to calculate moisture changes, the equation becomes

$$M_1 - M_2 = \frac{1}{b} (X_1 - X_2) \quad (2)$$

where $M_1 - M_2$ represents a change in moisture volume, b is the curve slope as previously defined, and X_1 and X_2 are counting rates at the same location at two points in time. Simplified further

$$m = \frac{1}{b} x \quad (3)$$

where m is the moisture change and x is the change in counts at the same location at two different times.

At first this relationship was thought to be independent of the soil material, but experience has shown that soils vary in their ability to moderate and absorb neutrons. Thus, the applicability of equation (3) is limited by the manner of deriving the b coefficient, i. e., the calibration method. Usually, the probe containing the radioactive source is calibrated by determining moisture volume gravimetrically after drying samples of the soil at 105° to 110° C.

However, soils retain varying amounts of water after drying, depending on mineral characteristics and texture (3, 4, 6). This tightly-held water also slows neutrons. If a probe is calibrated in soils of varying texture and mineralogy, as is often the case, it is possible to obtain different calibration curve slopes merely by changing the drying temperature.^{1/} Furthermore, differences in neutron absorbers in the various soils used may increase or decrease the slope, thus adding or subtracting from the bias produced by failure to remove all water from gravimetric samples.

No fully satisfactory method has been reported for checking the gravimetrically derived b coefficients used to calculate soil moisture changes with time. A new calibration procedure is reported here which is believed to avoid much of the difficulty just discussed.

METHODS AND MATERIALS

The calibration method involves measuring both the volume of water required to displace air from a known volume of soil and the slow neutron count before and after addition of the water. Moisture volume and neutron counting rate changes are computed and used to obtain the calibration curve slope by solving for b in equation (3). Since the method does not involve volumetric sampling and drying of soil, differences in b coefficients between soils can be attributed directly to moderation and absorption characteristics of the soil rather than to variations in water content remaining after drying.

Slopes were determined for four Piedmont soils, Lloyd clay B horizon, Cataula clay B horizon, Cataula sandy loam C horizon, and Appling sand A horizon. Uniformity during the study was maintained by using the same equipment throughout. Slow neutron counting rates were obtained with a P-19 moisture probe and Model 2800 scaler. A 280-gallon steel drum 40 inches in diameter and 50 inches in height contained a vertical, centrally located, 1-5/8-inch seamless steel access tube (fig. 1). The drum was calibrated so that the volume of soil held by the drum could be determined to about 0.01 percent. A 55-gallon barrel was used to meter water into the drum.

Soil was passed through a $\frac{1}{2}$ -inch mesh screen, mixed thoroughly, and packed to a uniform moisture and density. After the drum had been filled, a 3-minute count was taken with the probe resting on the bottom. Successive counts were made at 2-inch intervals as the probe was raised to the soil surface, providing a measure of moisture uniformity in the mid-portion of the drum. It was assumed that this measure was unaffected by soil-air interface effects.

Next, a measured volume of water was forced under low pressure into the base of the drum, saturating the soil with minimum entrapment of air in the soil column. Water addition was terminated when free water was visible at the soil surface. The volume of water required for saturation was measured to 0.01 percent, and, to obtain moisture change, volume of water added was divided by soil volume. This procedure was followed for each soil studied.

^{1/} Unpublished data. Coweeta Hydrologic Laboratory and Calhoun Experimental Forest, Southeastern Forest Experiment Station.

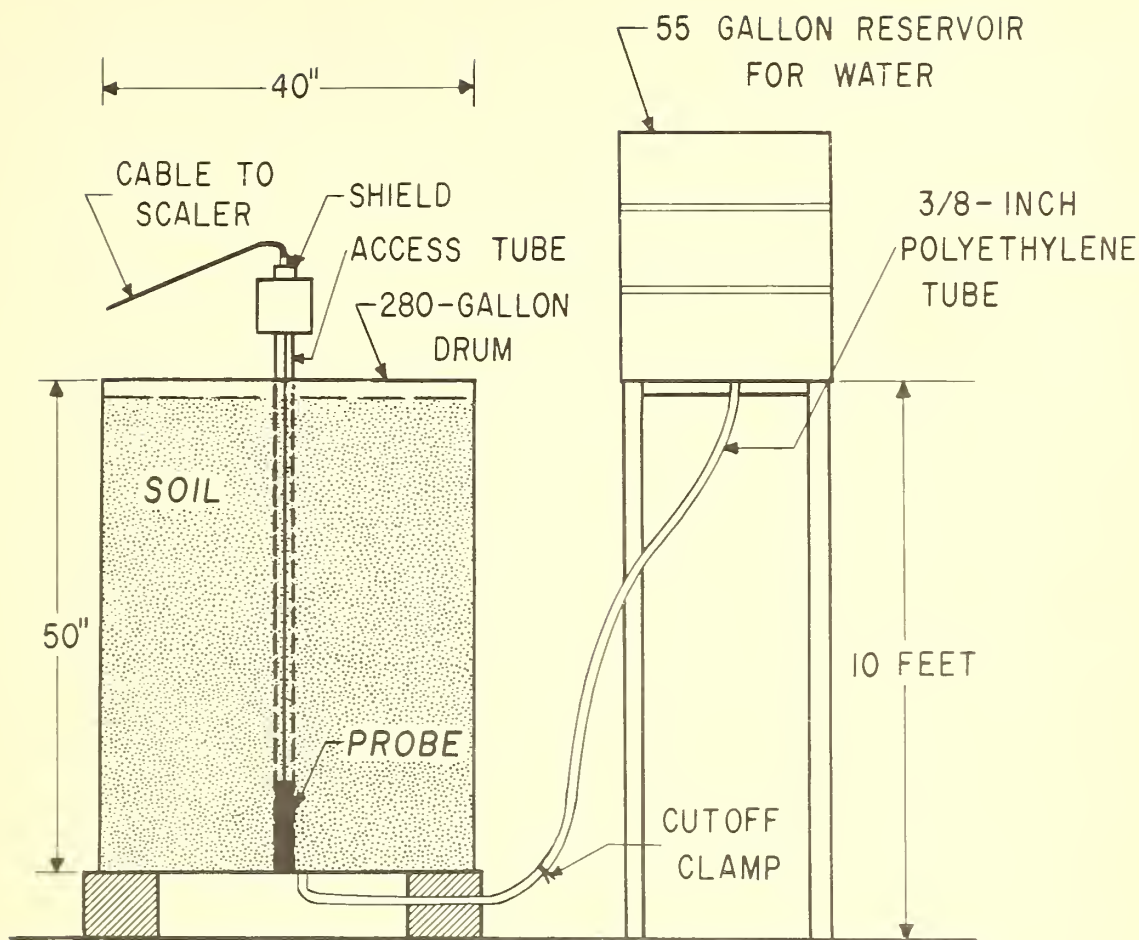


Figure 1.--Diagram of the arrangement of equipment used in calibrating a P-19 moisture probe by the water-addition method. The soil column is saturated from below under pressures up to 380 cm of water.

Soil-air interface effects were apparent at the top and bottom of the soil column, but within the center one-third of the drum variation in counting rate between 2-inch intervals was generally less than 1 percent by volume. Variation was attributed to slight differences in soil density and to small quantities of trapped air remaining after saturation. Count rates in the center one-third of the drum were used to calculate the mean change in counts. Since a uniform procedure was used in packing the soil, moisture changes throughout the drum were assumed to be uniform also.

This two-point calibration over a short range in moisture content assumes a linear relation between counts and moisture content. There is no reason to expect any other relation for probes of this design, since all reported curves are essentially linear between about 10 and 50 percent moisture. Also, previous gravimetric calibration of this particular probe gave a linear response throughout the moisture range studied.

RESULTS AND DISCUSSION

The b coefficients obtained by water-addition calibration appeared to fall into separate groups depending on mineralogy and texture of the soil fractions (table 1). Coefficients for the Cataula and Lloyd soils were not

Table 1. --Calibration curve b coefficients for several Piedmont soils as measured by the water-addition method

Soil series	Texture	Horizon	b coefficient
			cpm
Lloyd	Clay	B	199
Cataula	Clay	B	202
Cataula	Sandy loam	C	202
Cataula	Sandy loam	C	204
Appling	Sand	A	238
Appling	Sand	A	241

significantly different, and deviated from the mean by only ± 2 counts per percent moisture volume. Variance among Appling sands appeared to be of about the same magnitude, but b coefficients differed significantly from those of Cataula and Lloyd series. If these coefficients were used to calculate moisture change, the error for either soil group would be less than 0.5 percent moisture for a change from saturation to approximately wilting point.

Differences between b coefficients are attributed to greater neutron absorption by the Cataula-Lloyd series. The b coefficient for soils which are relatively efficient neutron absorbers will be less than

that for inefficient neutron absorbers because these effects are proportional to slow neutron density. The b coefficient determined by the water-addition method contains the effect of absorbers, and since other factors associated with calibration are held constant, coefficient differences between soils can be ascribed directly to absorber differences.

Coefficients determined gravimetrically, by water-addition, and by the manufacturer differed appreciably (fig. 2). The discrepancy is attributed mostly to the failure of the arbitrarily selected drying temperature (105° to 110° C.) to remove all hygroscopic and crystalline water from the soil. The amount of water retained by soil after drying varies with texture and mineralogy of the soil fraction. The effect of tightly bound water is, of course, included in the counting rate, and its effect is appreciable in some Piedmont soils (table 2). Thus gravimetric calibrations derived from soils of varying textures will contain a positive but unpredictable bias. Moisture content changes based on calibration using arbitrary drying temperatures, although reproducible, may be in error by as much as 36 percent. It appears that the warnings against using more than one type of soil material to derive gravimetric calibration curves (6) are justified for two reasons: (a) They are customarily based on the removal of water from soils by arbitrary drying temperatures. (b) Even if such error were reduced by higher drying temperatures or adjustment, the neutron absorption characteristics of various soils, as demonstrated here, may still dictate separate calibration when precise results are needed.

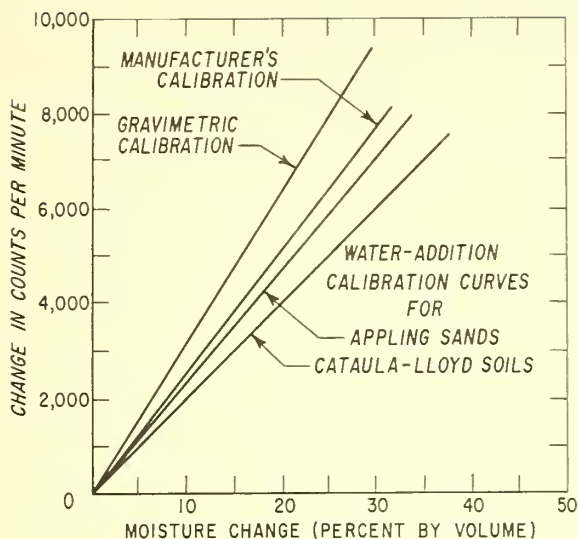


Figure 2. --Comparison of the effect of the b coefficient determined by two methods of calibration on calculated moisture change.

Table 2. --Slow neutron counting rate measured in 5-gallon containers filled with soil dried at 105° C.

Soil series	Horizon	Texture			Counting rate ^{1/}
		Sand	Silt	Clay	
- - <u>Percent</u> - -					<u>cpm</u>
Appling	A	87	9	4	26
Cataula	C	57	33	10	38
Cataula	C	66	17	17	42
Cataula	B	37	14	49	207

^{1/} Counting rate above background count.

SUMMARY

Measuring soil moisture changes from one time to another by the neutron method requires that the calibration slope coefficient accurately represent the change in count rate per unit change in moisture content.

A new method is presented which allowed a check on slope coefficients derived from gravimetric calibrations. Slopes were obtained experimentally for four Piedmont soils by the addition of a known volume of water to a known volume of each soil. The count rate per unit change in moisture content differed between Appling and Cataula-Lloyd series by about 17 percent, and the difference was attributed to neutron absorbing characteristics of the soils studied.

Coefficients obtained by water addition differed from those obtained gravimetrically by as much as 36 percent, depending on soil series. Differences were attributed to (a) bias arising because drying temperatures used in gravimetric calibration failed to remove all soil water, and (b) failure of the gravimetric method to account for neutron absorber differences between soils.

LITERATURE CITED

- (1) Belcher, D. J., Cuykendall, T. R., and Sack, H. S.
1950. THE MEASUREMENT OF SOIL MOISTURE AND DENSITY BY NEUTRON AND GAMMA-RAY SCATTERING. Civil Aeronautics Admin. Tech. Devlpmt. Rpt. 127, 20 pp., illus.
- (2) Gardner, Wilford, and Kirkham, Don
1952. DETERMINATION OF SOIL MOISTURE BY NEUTRON SCATTERING. Soil Sci. 73: 391-401.
- (3) Grim, Ralph E.
1952. CLAY MINERALOGY. 384 pp., illus. New York, Toronto, and London: McGraw-Hill Book Co., Inc.
- (4) Kelley, W. P., Jenny, H., and Brown, S. M.
1936. HYDRATION OF MINERALS AND SOIL COLLOIDS IN RELATION TO CRYSTAL STRUCTURE. Soil Sci. 41: 259-274.
- (5) van Bavel, C. H. M.
1958. MEASUREMENT OF SOIL MOISTURE CONTENT BY THE NEUTRON METHOD. Agr. Res. Serv., ARS 41-24, 29 pp., illus.
- (6) ——— Nielsen, D. R., and Davidson, J. M.
1961. CALIBRATION AND CHARACTERISTICS OF TWO NEUTRON MOISTURE PROBES. Soil Sci. Soc. Amer. Proc. 25: 329-333.

